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TETRAHEDRON FLOW BEAM GEOMETRY FOR MICROWAVE TUBES

NINTH TRIANNUAL REPORT

by

Oskar Heil

September 1969

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UNITED STATES ARMY ELECTRONICS COMMAND • FORT MONMOUTH, N.J. 07703

Contract DA 28-043-AMC-01961(E)

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BEAM GEOMETRY FOR
MICROWAVE TUBES

Report No. 9

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DISTRIBUTION STATEMENT

ABSTRACT

The purpose of this program is the study and evaluation of the tetrahedron beam geometry for application in microwave tubes. The construction of the first three cavity magnetic quadrupole focused klystron was completed and most of the time during this reporting period was used to set up the necessary test equipment to measure the high frequency performance of this tube. A few preliminary power and efficiency tests were made with efficiencies from 24.5 to 41% for output power from 14 to 84 Watt with operating voltage from 1200 to 2000 Volt. Between the first and second cavity a gain increase by a factor of 3 was obtained when the velocity modulation control was changed into a variable electron interception control reducing the first quadrupole field to the point of 20% beam interception. A surplus spark gap pulsed power supply was modified and tested for future use on demountable high power klystrons with magnetic quadrupole focusing. It will also be useful for adjusting the quadrupoles in permanent magnet focused klystrons.

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LIST OF FIGURES

PUBLICATIONS, LECTURES AND CONFERENCES

No publications were made and no lectures and conferences were held during this report period.

1.0 FACTUAL DATA

1.1 TEST ARRANGEMENT FOR THE DEMOUNTABLE MAGNETIC QUADRUPOLE FOCUSED KLYSTRON

During this Reporting Period most of the time was spent in setting up the test equipment for the first demountable klystron as it is shown in Figure 1. A circulating water calorimetric power meter is positioned directly inside the klystron output cavity which simplifies this measured by eliminating high frequency coupling and matching sections at the tube output. A good accuracy of power measuring is obtained by this means.

1.2 THE VACUUM SYSTEM

The 200 liter per second sputter ion pump maintains a vacuum of 2×10^{-7} torr. The ten inch diameter eighteen inch high pyrex glass cylinder assures sufficient distance from the pump magnets to prevent any magnetic disturbance of the electron beam and provides at the same time a good vacuum reservoir. The ion pump is shut off with a six inch gate valve. A small side valve allows the tube to go down to air and to be repumped to rough vacuum before the gate valve is reopened.

A cathode renewal can be done in half a day. The klystron is set upside down on a wooden stand as shown in Figure 2. Four little flat springs are turned sideways and the cathode comes off without disturbing

the alignment of the beam forming electrode. After scraping the coating off, the cathode is resprayed and inserted again. The cathode had to be renewed because of several electric power failures, which cut off the pump. To prevent this time consuming operation, a relay system was built switching the pump supply to a 12 Volt car battery with a 115 Volt A.C. converter in case of power failure.

1.3 THE HIGH FREQUENCY DRIVER

A surplus cavity type triode oscillator T-85/APT-5 was modified for 115 Volt A.C. to deliver the drive frequency of 1325 megahertz. A separate anode power supply was used. The frequency is monitored by a coaxial cavity frequency meter (Sperry 12Li). A double stub tuner is used for matching to the klystron input cavity.

1.4 CAVITY MONITORING

All three cavities have an extra coupling loop for monitoring the relative high frequency voltage. Three crystal cartridges are mounted directly on top of the klystron plate. The three indicating meters can be seen in Figure 1 on the wall shelf.

1.5 POWER MEASURING ARRANGEMENT

The high frequency output power is converted into heat within the output cavity and measured calorimetrically. Water with 6.5% sulphuric acid is used as power

dissipating liquid. The acid increases the specific losses. The 9 mm diameter quartz glass tubing containing the liquid penetrates only 6 mm into the cavity space for proper loading. The in and out motion of the tubing varies loading without noticeably de-tuning the cavity, which is not the case with pure water. The specific heat of this acid-water mixture was carefully measured. The density is 1.04. The specific heat is decreased by 4%. The Watt per ccm, degree C remain the same as for water which is 4.18 Watt. The decrease in specific heat is compensated for by the increase in density.

The constant flow of liquid is obtained by producing a constant liquid level difference of about 6 feet between the upper and lower glass container (See Figure 1). An acid proof plastic pump with a magnetically driven impeller circulates the liquid. An overflow in the upper container keeps the liquid level constant and permits the excess liquid to flow into the lower container.

In continuous operation the temperature of the circulating liquid rises above room temperature and loses approximately 0.1 to 0.2°C by heat conduction in the water-cooled tube body at the place of entrance of the vacuum. The cooling water is at tube temperature when leaving the structure. A glass heat exchanger was introduced utilizing this water to bring the acid-water to tube temperature before entering the measuring device. This refinement made the power measurements very precise and reproducible.

Another possible error was also checked. The tantalum foil collector is white hot in operation. Some of the heat radiation enters the output cavity through the output gap and could heat the acid water. No heating of the acid-water was noticeable with the high frequency drive turned off and the electron beam still heating the collector.

The acid-water flow rate is determined by an exchangeable glass nozzle at the lower container and adjusted to about 1 to 2 ccm per second. The temperature difference is measured with two precision thermometers, showing tenths of a degree C. Before reading the temperature the power is peaked by observing the output cavity monitoring meter and optimizing drive level and input and output cavity tuning. The loading is systematically varied by changing the penetration of the load tube into the cavity. This variation is not very critical and seems to indicate poor beam coupling in the output gap which is rather wide. The drift tube and gap geometry is drawn in Figure 3 in actual dimensions. It shows the cross-sections in two perpendicular planes, one in solid and one in dotted lines.

1.6 D.C. POWER SUPPLIES

The supply used for the magnetic quadrupoles is a 2 Volt battery. The control panel (in Figure 1 to the right under the wall shelf) has coarse and fine regulating resistances for all eight coils of the two quadrupoles.

The meter can be switched to any of the coil circuits. Fine regulation was not needed. The best setting shows equal current in all the coils of a quadrupole. The total power consumption of the coils was 17 milliwatts for the tube operating at 2000 Volts with 200 Watts in the electron beam which is about 10000 times the magnet power. The magnetic field varies with the square root of the beam voltage. The magnetic power consumption is therefore proportional to the beam voltage whereas the beam energy varies as the five halves power of the beam voltage.

The anode power supply is shown in Figure 1 on the left and on top of it on an isolation board is a small d.c. supply used for the beam-forming voltage. This supply was not necessary for proper tube operation. Because of the small spacing between cathode and beam-forming electrode they could be operated at the same potential.

Another d.c. supply was used to give the collector a positive voltage against the tube body which is at ground potential. This potential holds back slow secondary electrons from reaching the tube body. The electron beam transmission can be measured this way. But this measurement is not too reliable, because secondaries released at the output gap reach the collector. A beam transmission in excess of 100% can be measured with the tube in operation if the collector is made sufficiently

positive. However this indicates interception at the output gap with a consequent release of secondary electrons.

1.7 PRELIMINARY TEST RESULTS

The tube was operated with an estimated beam transmission of 90% to 100%. Exact transmission measurements were not possible, as mentioned above. The high-frequency drive, the tuning of the first and last cavity and the load coupling were optimized giving the following results:

Volt	mA	Beam Watt	Output Watt	Efficiency
1200	48	57.6	14.1	24.5%
1300	54	70.2	17.45	24.9%
1400	60	84.0	21.4	25.5%
1500	67	100.5	27.7	27.5%
1600	73	116.8	35.3	30.2%
1800	88	158.4	55.5	35.0%
2000	102	204.0	84.0	41%

Higher beam power was not used because the tantalum foil collector ran too hot close to the glass wall, and some electron focusing could melt it exposing the glass to the energetic electron beam. In order to eliminate the problem a water-cooled collector is planned. Higher efficiencies are expected after optimizing the gap geometry.

1.8 EFFECT OF DETUNING THE MIDDLE CAVITY

The middle cavity of a klystron should be tuned higher than the operating frequency for best efficiency. This effect is more pronounced at high power levels, where greater degrees of detuning are possible. The tube was checked at 1500 Volt operation with about 25 Watt output. The efficiency increased from 24.3% at resonance to a maximum of 27.9% when the middle cavity was tuned higher by 2 Megahertz. Since the middle cavity has a fixed frequency in the klystron, the driver and input and output cavity frequency were actually changed.

1.9 HIGHER GAIN BY INTERCEPTION MODULATION

If the focusing magnetic field of the first quadrupole was reduced, electron interception started in the first drift tube. This interception increased the voltage gain from first to second cavity. At 20% beam interception, this gain reached a maximum of a three times greater value than the velocity modulation gain with no interception. The interception produced by an increased quadrupole field did not show this effect. This tube is not designed for interception modulation. The cross modulation is rather suppressed by the curved modulation gap (See Figure 3). Considerable improvement in greater gain should be obtained with an opposite curvature of the first control gap. This gain is a result of the refined electron optics and has no practical significance for this

tube because of the great loss of electrons by interception.

1.10 SPARK PULSE FOR PERMANENT MAGNET QUADRUPOLE ADJUSTING AND FOR HIGH POWER KLYSTRON TESTING

For adjustment of the focusing system of a high power klystron, it is necessary to operate it at lower average power. Full power can be turned on only when the electron beam clears all the drift tubes. With a permanent magnet focused quadrupole klystron, the average power can only be reduced by a pulser of small duty cycle. A surplus stored energy spark pulser (MD-32/TPS-1B Modulator) was therefore modified for our future use and tested. 5 of the 7 rotary spark gap pins were removed. The remaining 2 pins give 60 pulses per second of 5 micro second duration which are nice and square into a 14 ohm load with about 5000 Volts and 300 Amperes. Most of the energy in our applications will be shunted and dissipated in a load resistance.

2.0 CONCLUSIONS

The main purpose of this research program is the reduction of the magnetic focusing field energy in klystrons. This has been demonstrated experimentally with 17 milliwatt power consumption in the electromagnetic quadrupole which could be replaced with small permanently magnetized quadrupoles with no power consumption.

The efficiency is similar to standard type low power klystrons but is expected to improve by optimizing the drift tube and gap geometry.

Light weight quadrupole focused klystrons will not show the frequency-power limitation of electrostatically focused klystrons which is due to field emission in the lenses. They also will operate at higher perveances.

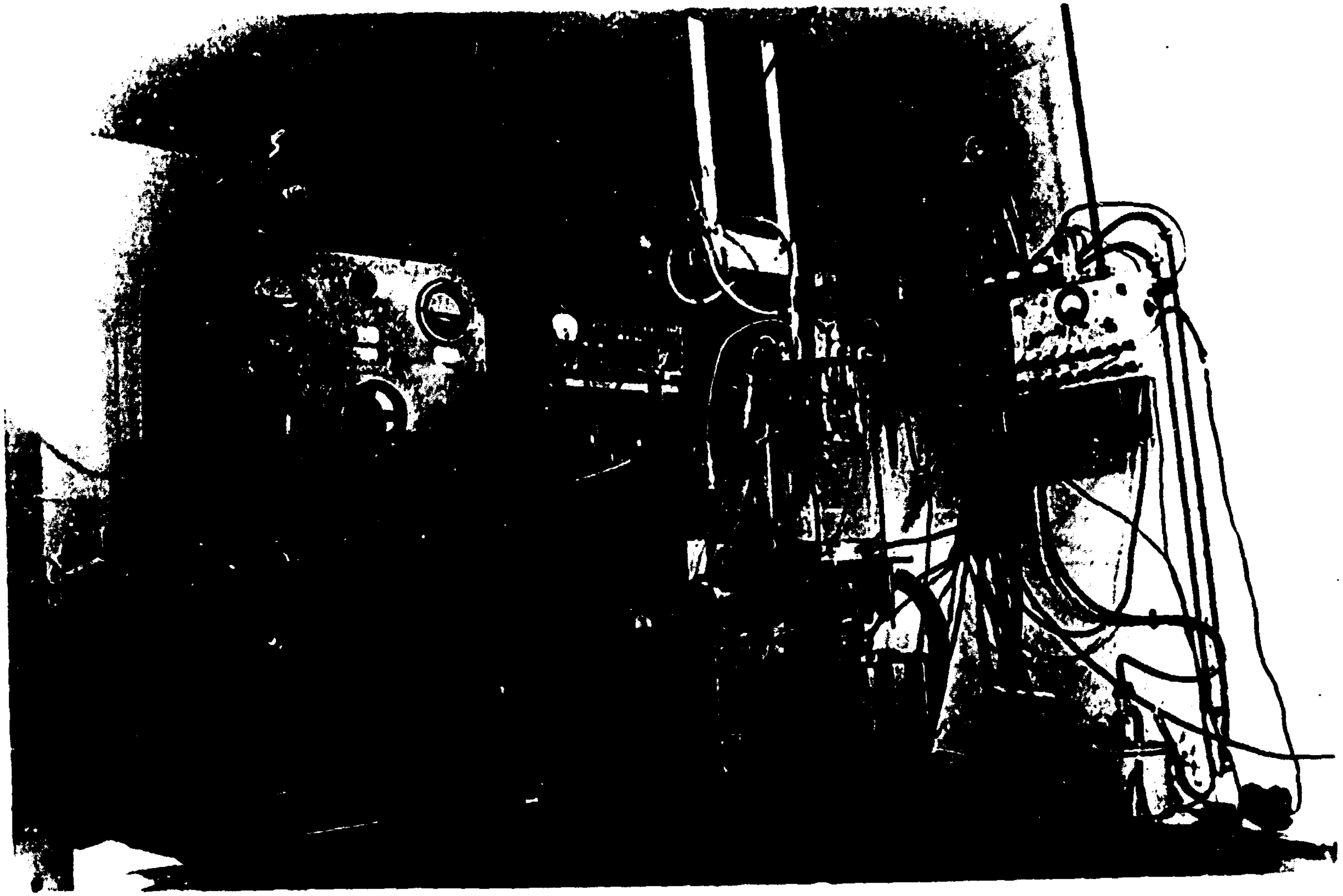
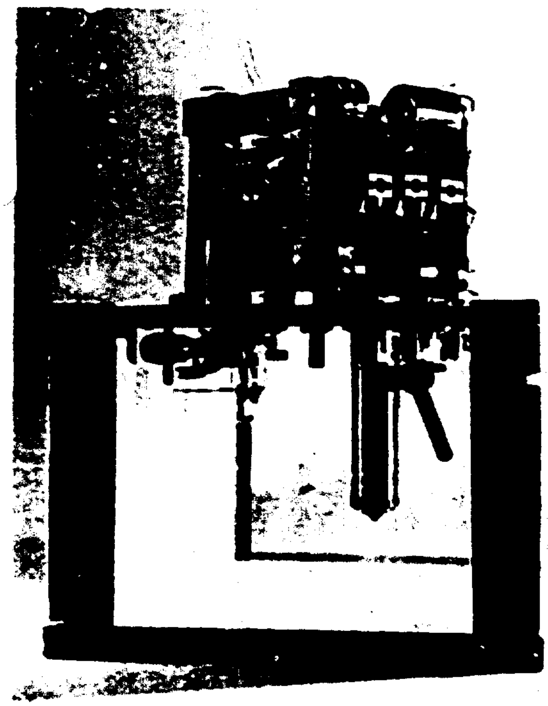


FIGURE 1.

Test Arrangement of the Continuously Pumped, Demountable Magnetic Quadrupole Focused Klystron.



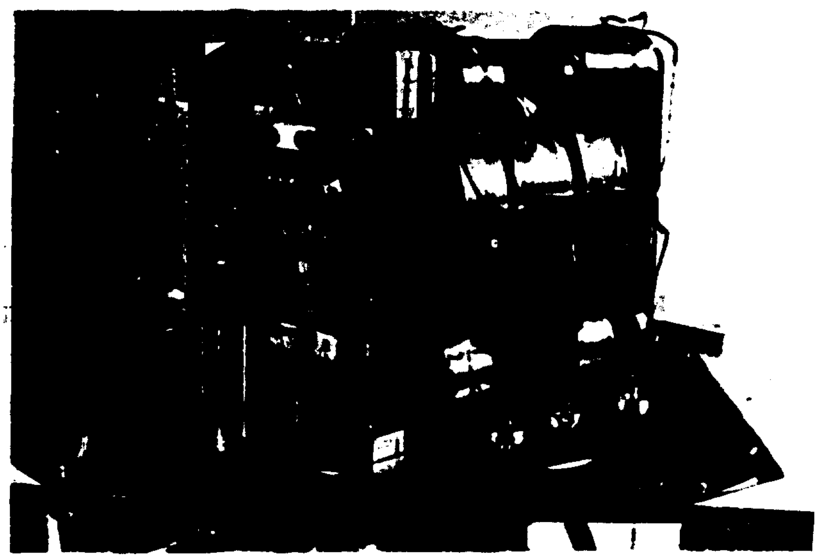


FIGURE 2.

Magnetic Quadrupole Focused Klystron

Sitting on Wooden Stand for Cathode Renewal.

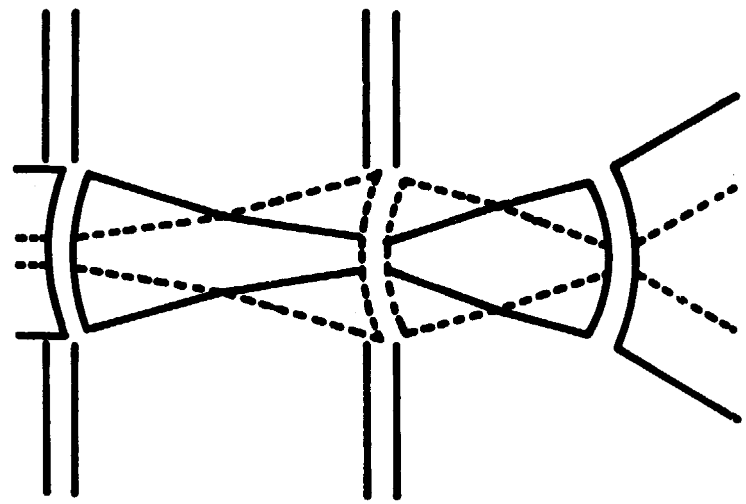


FIGURE 3.

Drift Tube Geometry of Magnetic Quadrupole Focused Klystron
Cross-Sections in two Perpendicular Planes (solid and dotted)
Location of Quadrupoles indicated by Double Lines. Scale:1:1

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